AD-A175 461 SYNTHESIS AND PROPERTIES OF NOVEL MULTILAYER SEMICONDUCTOR STRUCTURES(U) NORTH CAROLINA STATE UNIV AT RALEIGH J F SCHETZINA 12 OCT 86 ARO-20680 2-EL-A 1/1

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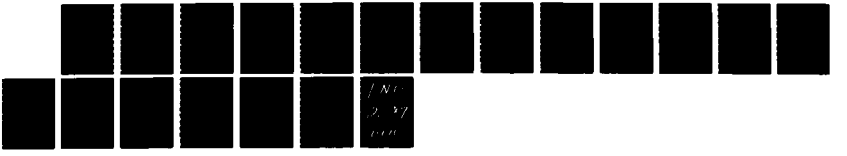

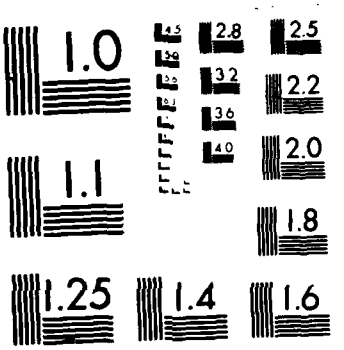

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4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)
ARO 20680.2-EL-A

6a. NAME OF PERFORMING ORGANIZATION
North Carolina State University

6b. OFFICE SYMBOL (If applicable)

7a. NAME OF MONITORING ORGANIZATION
U. S. Army Research Office

6c. ADDRESS (City, State, and ZIP Code)
Raleigh, NC 27695

7b. ADDRESS (City, State, and ZIP Code)
P. O. Box 12211
Research Triangle Park, NC 27709-2211

8a. NAME OF FUNDING / SPONSORING ORGANIZATION
U. S. Army Research Office

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State, and ZIP Code)
P. O. Box 12211
Research Triangle Park, NC 27709-2211

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
SYNTHESIS AND PROPERTIES OF NOVEL MULTILAYER SEMICONDUCTOR STRUCTURES (FINAL REPORT)

12. PERSONAL AUTHOR(S)
J.F. Schetzina

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
FINAL	FROM 7/83 TO 7/86	10/12/86	18

16. SUPPLEMENTARY NOTATION
The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
MBE, Infrared Materials, HgCdTe, Quantum Well Structures

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A mercury-compatible molecular beam epitaxy system has been designed and constructed at NCSU. The system has been used to prepare and study a variety of novel quantum well structures and superlattices. These studies have led to a number of research publications in this area, as described in the final report.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
J.F. Schetzina	(919) 737-3314	

DD FORM 1473, 84 MAR
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SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

ARO 20680.2-EL

FINAL REPORT

ARO PROPOSAL NUMBER: 20680-EL-A

PERIOD COVERED BY REPORT: July, 1983 - July, 1986

TITLE OF PROPOSAL: Synthesis and Properties of Novel Multilayer Semiconductor Structures

CONTRACT OR GRANT NUMBER: DAAG29-83-K-0102

NAME OF INSTITUTION: North Carolina State University

AUTHOR OF REPORT: J.F. Schetzina, Professor of Physics

I. SUMMARY OF RESEARCH ACCOMPLISHMENTS (1984-1986) UNDER DARPA/ARO SUPPORT

(J.F. Schetzina and J.W. Cook, Jr., Co-Principal Investigators)

A. MBE GROWTH OF HG-BASED FILMS, QUANTUM WELL STRUCTURES, AND SUPERLATTICES

We have designed and constructed at NCSU a mercury-compatible MBE system which features a cryopumped UHV main chamber, a specially design Hg source, a load-lock for introducing and retrieving substrates and epilayers, and a preparation/analysis chamber which features a high temperature (1000 C) substrate bakeout station, a sputter etch station, a reverse view LEED facility, and a metallization station. The system became operational in February, 1984. Since that time, the MBE system has been successfully employed to grow high mobility HgCdTe, high mobility HgTe, HgTe-CdTe superlattices, and more recently Hg-based diluted magnetic semiconductor films (HgMnTe) and superlattices (HgMnTe-HgTe). This work has been extremely successful as is evident by the number of papers presented at scientific meetings, by the invited talks given at many universities and industrial laboratories, and by the numerous articles in refereed journals of physics and materials science that this work has produced. MBE growth of Hg-based

compounds and quantum well structures will continue to be emphasized at NCSU in the months ahead.

B. CONTROLLED SUBSTITUTIONAL DOPING OF CdTe

We have invented a new technique for the doping of compound semiconductor films: photo-assisted molecular beam epitaxy. This new technique has been employed to obtain immediate and significant improvements in the control of the electrical properties of n-type and p-type CdTe. In the photoassisted MBE process, the substrate is illuminated during film growth. In our initial work, the output from an argon ion laser was used to illuminate the substrate during CdTe:In film growth. In connection with the substitutional doping process, the rationale for this approach is to provide, by means of the incident photon beam, the energy required to surmount surface potential barriers which might ordinarily prevent or limit the incorporation of the dopant species at tetrahedrally-bonded sites, and thus increase the degree of dopant activation. Note that each of the photons in such a laser beam carry approximately 2.4 eV of energy, which is much larger than the thermal interaction energies (phonon energies) available at substrate temperatures normally employed in MBE film growth of CdTe and other semiconductors. As a consequence, the photon beam may be expected to have a pronounced influence on the surface chemisty during film growth through modification of surface bonds, conversion of surface molecules into atoms, etc.

Our initial experimental results are most encouraging. Both n-type and p-type CdTe films have been growth. SIMS studies of n-type layers coupled with Hall effect measurements have provided evidence that the photo-assisted MBE technique gives rise to essentially 100% activation of the dopant when optimum growth conditions are employed. Pronounced changes in the

luminescence spectrum of CdTe also accompany doping, which provide additional direct evidence that highly activated layers have been grown. Antimony has been used as a dopant for growth of p-type CdTe. Again, when grown under illumination, doped epilayers result, as determined by hall and lumininescence experiments.

We have also recently used the photo-assisted MBE technique to prepare the world's first thin film p-n junctions of CdTe. These junctions show good rectification properties. This accomplishment is of particular significance since n-type and p-type CdTe may be used in a double heterostructure involving HgCdTe or HgTe-CdTe superlattices. Because of the band gap variability of the Hg-based compounds with Hg content, such structures might be employed to create new solid state light sources and/or detectors which could operate at selected wavelengths throughout the infrared spectral region.

C. GROWTH OF CdMnTe-CdTe MULTILAYER STRUCTURES AND SUPERLATTICES

Continuing progress has been made in the growth and study of CdMnTe-CdTe quantum well structures. In particular, a number of superlattices have been prepared which exhibit stimulated emission when optically pumped.

In collaboration with D. Heiman and E. Isaacs of the MIT National Magnet Laboratory, magnetically tunable stimulated emission has been observed in dilute magnetic semiconductor superlattices. The tuneability range of the emission was found to be much larger (by a factor of fifty) than for that of non-magnetic semiconductors. This is due to the magnetic exchange interaction which occurs between the Mn ions and the conduction band electrons and valence band holes. This interaction gives rise to large positive electronic g-factors so that the band gap of of DMS materials changes appreciably under an applied magnetic field. This collaborative work is continuing at the

present time.

D. SUBSTITUTIONAL DOPING OF CdMnTe FILMS AND CdMnTe-CdTe SUPERLATTICES

Very recently, we have successfully used the photo-assisted MBE technique to grow conducting CdMnTe:In films. Electrical and optical characterization studies of these new doped layers are currently being completed. In addition, we have grown the first conducting superlattices of CdMnTe-CdTe by using a modulation doping technique under photo-assisted MBE conditions. These experiments, along with accompanying characterization experiments, are continuing and will be emphasized during the months ahead.

II. SUMMARY OF RESEARCH PUBLICATIONS UNDER DOD SUPPORT (1984-1986)

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46. "Quantum Well Structures and Superlattices Composed of DMS Layers Grown by MBE", J.F. Schetzina, to be published in the Proceedings of the 1986 Materials Research Society Symposium on Diluted Magnetic Semiconductors.

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17. "Molecular Beam Epitaxy of II-VI Semiconductors", J.F. Schetzina, Ford Aerospace Laboratory, Newport Beach, CA (1985).

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21. "Strain Effects in II-VI Superlattices", D.K. Blanks, Texas Instruments Central Research Laboratory, Dallas, TX (1985).

22. "Quantum Well Structures of CdMnTe-CdTe", D.K. Blanks, Santa Barbara Research Institute, Santa Barbara, CA (1985).

23. "Strain Effects in CdMnTe-CdTe Quantum Wells", D.K. Blanks, Hughes Research Laboratory, Dallas, TX (1985).

24. "Bonding Defects in a-Si Alloys", J.W. Cook, Jr., 7th Photovoltaic Advanced Research and Development Project Review Meeting (SERI), Denver, CO (1986).

25. "The Growth of HgTe-CdTe Superlattices by Molecular Beam Epitaxy", Materials Research Society Workshop, Chapel Hill, NC (1986).

26. "Growth and Properties of CdTe on Sapphire and GaAs Substrates", J.F. Schetzina, ARO Infrared Materials Symposium, Raleigh, NC (1986).

27. "Synthesis and Properties of Novel Semiconductor Multilayer Structures", J.F. Schetzina, ARO Infrared Materials Symposium, Raleigh, NC (1986).

28. "Quantum Well Structures and Superlattices Composed of II-VI Semiconductors", J.F. Schetzina, Materials Research Society Symposium on Compound Semiconductors, Palo Alto, CA (1986).

29. "MBE Growth of II-VI Semiconductor Films and Superlattices", J.F. Schetzina, DARPA Focal Plane Array Symposium, Washington, DC (1986).

30. "Submicron Heterostructures of DMS Materials", J.F. Schetzina, Purdue University, (1986).

31. "Recent Advanced In MBE Growth of II-VI Semiconductors", J.F. Schetzina, DARPA/MRC Symposium on Compound Semiconductors, La Jolla, CA (1986).

32. "Quantum Well Structures and Superlattices Composed of II-VI Materials Containing Magnetic Ions", J.F. Schetzina, KOSEF/NSF Joint Seminar on the Physics of Semiconductor Materials and Applications, Seoul, Korea (1986).

33. "MBE Growth of II-VI Semiconductor Films and Superlattices", 1986 Seoul International Symposium on the Physics of Semiconductors and Its Applications", J.F. Schetzina, Seoul, Korea (1986).

34. "Novel Structures Composed of II-VI Semiconductors", J.F. Schetzina, Naval Research Laboratory, Washington, DC (1986).

35. "MBE Growth of II-VI Films, Quantum Well Structures, and Superlattices, J.F. Schetzina, Texas Instruments Central Laboratory, Dallas, TX (1986).

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CONTRIBUTED PAPERS PRESENTED AT PROFESSIONAL MEETINGS (1984-1986)

1. "Properties of CdTe/Sapphire Epilayers Grown by Molecular Beam Epitaxy", R.W. Yanka, N.C. Giles, R.N. Bicknell, T.H. Myers, and J.F. Schetzina, BAPS 29, 233 (1984).

2. "Reflectance of AlAs-GaAs and InGaAs-GaAs Superlattices", D.K. Blanks, W.D. Laidig, and J.F. Schetzina, BAPS 29, 258 (1984).

3. "Photoluminescence Studies of CdTe Films", N.C. Giles-Taylor, R.N. Bicknell, T.H. Myers, and J.F. Schetzina, BAPS 29, 477 (1984).

4. "Properties and Applications of CdTe/Sapphire Epilayers Grown by Molecular Beam Epitaxy", T.H. Myers, N.C. Giles-Taylor, R.W. Yanka, J.W. Cook, Jr., S.R. Jost, H.S. Cole, H.H. Woodbury, and J.F. Schetzina, 1984 U.S. Workshop on MCT, San Diego, CA.

5. "Photoluminescence of CdTe: A Comparison of Bulk and Epitaxial Material", N.C. Giles-Taylor, R.N. Bicknell, D.K. Blanks, T.H. Myers, and J.F. Schetzina, 1984 U.S. Workshop on MCT, San Diego, CA.

6. "Properties of CdMnTe-CdTe Superlattices Grown by Molecular Beam Epitaxy", R.N. Bicknell, N.C. Giles-Taylor, D.K. Blanks, R.W. Yanka, E.L. Buckland, and J.F. Schetzina, 3rd International Conference on Molecular Beam Epitaxy, San Francisco, CA (1984).

7. "Observation of the CdTe-GaAs Interface by High Resolution Transmission Electron Microscopy", N. Otsuka, L.A. Kolodziejski, R.L. Gunshor, S. Datta, R.N. Bicknell, and J.F. Schetzina, Materials Research Society Symposium on Layered Structures, Boston, MA (1984).

8. "Properties of CdMnTe-CdTe Quantum Well Structures and Superlattices Grown by MBE", R.N. Bicknell, N.C. Giles-Taylor, D.K. Blanks, R.W. Yanka, E.L. Buckland, and J.F. Schetzina, Materials Research Society Symposium on Layered Structures, Boston, MA (1984).

9. Growth and Characterization of II-VI Alloy Crystals, K.Y. Lay, B. Breithaukpt, N.C. Giles-Taylor, K.J. Bachmann, and J.F. Schetzina, Electrochemical Society Symposium, New Orleans, LA (1984).

10. "Double Crystal X-Ray Diffractometry and Topography Study of CdTe/Sapphire and CdTe/GaAs Epilayers Grown by Molecular Beam Epitaxy", R.N. Bicknell, K.A. Harris, J.W. Cook, Jr., W.H. Takei, and J.F. Schetzina, BAPS 30, 209 (1985).

11. "Low Temperature (1.8 K) Photoluminescence Studies of CdMnTe-CdTe Superlattices in Large Magnetic Fields", A. Petrou, J. Warnock, R.N. Bicknell, N.C. Giles-Taylor, and J.F. Schetzina, March APS Meeting, Baltimore, MD (25-29 Mar 1985).

12. "Stimulated Emission from a CdMnTe-CdTe Quantum Well Structure", N.C. Giles-Taylor, N.G. Anderson, R.N. Bicknell, W.D. Laidig, and J.F.

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26. "Controlled Substitutional Doping of CdTe Films", R.N. Bicknell, N.C. Giles, J.F. Schetzina, and C. Hitzman, 1986 U.S. Workshop on MCT, Dallas, TX (1986).

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28. "Far-Infrared Magneto-Absorption in HgTe/CdTe and $Hg_{1-x}Mn_xTe$/HgTe Superlattices", M. Dobrowolska, Z. Yang, H. Luo, J.K. Furdyna, K.A. Harris, J.W. Cook, Jr., and J.F. Schetzina, 1986 U.S. Workshop on MCT, Dallas, TX (1986).

29. "Transmission Electron Microscope Study of Hg-Based Multilayer Structures", N. Otsuka, K.A. Harris, J.W. Cook, Jr., and J.F. Schetzina, 1986 U.S. Workshop on MCT, Dallas, TX (1986).

30. "Far-Infrared Magnetospectroscopy of HgTe and $Hg_{1-x}Mn_xTe$ Monolayers Grown by MBE", H. Luo, M. Dobrowolska, Z. Yang, J.K. Furdyna, K.A. Harris, J.W. Cook, Jr., and J.F. Schetzina, 1986 U.S. Workshop on MCT, Dallas, TX (1986).

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32. "Controlled Substitutional Doping of CdTe Films", R.N. Bicknell, N.C. Giles, and J.F. Schetzina, 1986 MRS Fall Meeting, Boston, MA (1986).

33. "Low Temperature Photoluminescence Study of Doped CdTe Films Grown by MBE", N.C. Giles, R.N. Bicknell, and J.F. Schetzina, 1986 MRS Fall Meeting, Boston, MA (1986).

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36. "Dilute Magnetic Semiconductor Superlattices Containing $Hg_{1-x}Mn_xTe$", K.A. Harris, S. Hwang, Y. Lansari, R.P. Burns, J.W. Cook, Jr., and J.F. Schetzina, 1986 MRS Fall Meeting, Boston, MA (1986).

37. "Growth and Characterization of High Quality, Low Defect, Subgrain Free Cadmium Telluride by a Modified Horizontal Bridgmen Technique", W. Allred, A.A. Khan, B. Dean, C.J. Johnson, N.C. Giles, and J.F. Schetzina, 1986 MRS Fall Meeting, Boston, MA (1986).

38. "Transmission Electron Microscope Study of Hg-Based Multilayer Structures", N. Otsuka, K.A. Harris, J.W. Cook, Jr., and J.F. Schetzina, 1986 MRS Fall Meeting, Boston, MA (1986).

39. "Characterization of MCT Epilayers and HgTe-CdTe Superlattice Layers", T.H. Myers, J.P. Kairns, K.A. Harris, S. Hwang, D.K. Blanks, J.W. Cook, Jr., and J.F. Schetzina, 1986 MRS Fall Meeting, Boston, MA (1986).

STUDENT DEGREES AWARDED (1984-1986)

Yacheng Lo, M.S. in Physics (1984)

Donald Hinson, M.S. in Physics (1984)

Robert A. Yanka, M.S. in Physics (1985)

Yamina Lansari, M.S. in Physics (1986)

Robert Newton Bicknell, Ph.D. in Phyics (1986)

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Nancy Giles-Taylor, Ph.D. student in Physics

Shang Hwang, Ph.D. student in Physics

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Tsung Han, Ph.D. student in Physics

Randall Harper, Ph.D. student in Physics

Yamina Lansari, Ph.D. student in Physics

Raymond H. Burns, M.S. student in Physics

William S. Enloe, M.S. student in Physics

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Robert N. Bicknell, Post-Doctoral Research Associate

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